REALITY AND THE PHYSICIST

Knowledge, duration and the quantum world

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Introduction

Philosophy is essential. For times immemorial it was used to impart some shape to views that were formless but illuminating, and it continues to do so in our day.

But today as in the past pure philosophy may also delude unwary minds. The unwary tend to have a craving for light and feel they have no time to waste on mere details. Like Descartes shaping his method, they believe (and at the outset, why should they not believe?) that the wings of thought are strong enough to carry them unerringly to the regions where truth prevails and that they have scant need of facts. So they turn to philosophy.

Some indeed are successful in following such a course. But nowadays in the scintillating, esoteric world to be found there many run the risk of getting lost. For *any* highly-polished but opaque way of speaking which sports with meaning and dismisses all that is familiar can easily be mistaken for the pronouncements of ultimate truth. And all too often the false glitter of preciosity beguiles the questing mind.

By contrast, many scientists will accept nothing but facts and 'formalisms' connecting facts. And among them, the physicists (principally the theoretical physicists) distinguish themselves further by their unequalled caution. This caution extends to the distrust – instinctive and acute – of any notion that is neither mathematically nor operationally defined. Even if they know full well that not everything can be defined, they are averse to making use of words from outside that realm; for considering their science, its methods, its progress and its history, they quite properly are on their guard against the shifts of meaning and the misunderstanding of many kinds that the slightest relaxation may let through. But however sound such an attitude is, for many it has the unfortunate effect of diverting them from the great questions, so much so that ultimately, for all the conceptual apparatus we now have at our disposal, it remains difficult to see these issues in their true light. This is all the more so in that there is a well-established tradition in the philosophy of science according to which that discipline should always operate from a position well upstream of current scientific research and restrict itself to reflecting on the general conditions which determine the validity of this research. From this it is plain that a philosophy which is less concerned with prescribing methods to the sciences or to criticising scientific values and more to better understanding the factual results that sciences provides us with is still to be created, or at least stands in need of considerable development.

It is essentially in this spirit that I shall seek in this book a better understanding of what is truly contained in the three great concepts, fundamental for human beings, of reality, causality and time. But if in broad outline this is the aim, achieving it will require a fairly lengthy journey. Such concepts can be, indeed have been, approached from various directions, each corresponding to defensible intellectual positions. These need to be examined without bias. It should come as no surprise to find detailed accounts here of methods and concepts which ultimately do not figure in the conclusions I arrive at. To defer judgement in such fashion clearly would have no place in a work that seeks popular appeal – it would impede the flow – but it is necessary for the balance and proper appreciation of any which, like this one, is an investigation and in which, in consequence, the author must provide precise reasoning in support of his arguments.

Indeed, it should be clear that this book is an investigation and not a popularisation. No judgement of value or of 'status' is implied by that statement. What is meant is simply that in common with any scientific or philosophical article, the book presents the author's own views and not those of 'the scientist' or 'the philosopher', taken generally; it is written with a view to making public some arguments, and ultimately some conclusions, which are not yet part of the corpus of knowledge or of the ideas of specialists. The only difference between it and such articles or other similar studies is one of form. In view of what has already been said, it seemed essential to make the book comprehensible to readers from disciplines other than my own. This has meant adding to the text some reminders of scientific notions that are known in principle but which not all readers may be able to recall immediately. These 'popularist passages' are few and short, and relieved of almost all mathematical apparatus (which however, it is necessary to appreciate, implicitly underlie them). References are given to works in which the mathematics is set out.

It may be objected that a philosophy of science which seeks a better understanding of factual results is primarily a matter for professional philosophers. Are they not in a better position to provide it than a scientist? There can be no clear-cut answer to that question, it seems to me. It is clearly true that philosophers have a great deal to say about the matter, and there is every reason to believe that in the future they will once more provide the major discussions. But it will be a difficult business for them to take over the reins and have everything under their control, for whether we like it or not things are rather more complex and problematic than at one point might have been thought. A clear division of labour, with the physicists dealing with the technical matters and the philosophers with the fundamentals, would work smoothly only if in practice it were possible to isolate the major questions at issue here – reality, causality, the reversibility or irreversibility of time – from matters of pure 'technique', and study them separately, without reference to technicalities. Now there is no logial inconsistency in conceiving a world in which this would be so, but it so happens that such a world is not ours. In the world we live in it has proved impossible to investigate in any valid way general questions we want to study, without referring at some point or other to particular developments which, though technical in structure, have effects that go beyond the mere framework of technique. In other words, alas, such investigations require some acquaintance with theoretical physics.

Some might find this disturbing. Is technical knowledge of theoretical physics also needed if one is to understand the *results* of the investigations recounted in this book? The reader will soon find out for himself that this is not the case (handsome creatures cover their skeletons . . .). Reassurances on another, more subtle point are also in order. Some might have initial trepidations that, like other physicists, I have devised some new formal mathematical structure of physics on an entirely personal basis, and have used it to produce the results in question. If this were indeed the case clearly it would tend to reduce the credibility of a book which purports to say little about the technical apparatus that underlies it. But again it should be appreciated that here things are quite different. What is left implicit in what follows is just the details of an array of formulae and equations which would take up much time and patience to review but which makes up the everyday stuff of present-day physics. It can be found in any textbook of quantum physics, and anyone who wants to do so can look up the details of the mathematical material of which only the substance is indicated here. What is original, or claims to be original, in this book are just the reflections, hypotheses and arguments bearing on the interpretation of this body of public knowledge.

If I had to sum up in a sentence or two the aims of this book, the following would be the least misleading: 'It was once thought that the notion of Being must be repudiated. Now that it has finally become apparent that to do so is to court incoherence, it is dismaying to find that in the interim it has become peculiarly difficult, if the facts are to be respected, to rehabilitate that notion.'

In the present context, 'difficult' does not mean 'impossible', as we shall see. Nevertheless, the summary statement just given may well seem somewhat opaque. It requires elaboration. The rest of this Introduction seeks to do just that. It both summarises some basic facts described in an earlier book* and outlines in preliminary fashion the main ideas of the present one.

To that end, the first step is to pass from 'near realism' to 'mathematical realism'. Niels Bohr described classical mechanics as being 'based on a well-defined use of images and ideas *which refer to events in everyday life*' (my italics). If we bear in mind that the ideas of force, point mass, mass,

* *In Search of Reality* [2], henceforth referred to as ISR and not to be confused with either 2A or 2B; in what follows I use the reference ISR [2] (the numbers in brackets refer to the Bibliography, p.272).

three-dimensional space, and absolute time are the foundations of classical theory, we must grant that his remark is pertinent. Of course there are those who would refuse to accept it, pointing out on the one hand that our everyday experience is that of weight, not that of mass, that of extended objects, not that of point masses, and so on, and on the other hand that classical mechanics includes notions (such as energy and acceleration) that are mental constructs. There is some truth in such observations. But in each case the later notion is defined by means of the former, which in turn are after all very simple idealisations of everyday experience. So if with respect to its fundamental notions we can say that classical mechanics distances itself from naive realism, this distance is rather small. And a realism that is based on the definitions of the kind we have just looked at may well be described as 'near realism'.

If for a moment we leave physics and turn to the 'macroscopic' sciences, it is easy to see that in our own day they are still in practice dominated by near realism. This of course explains why the need to go beyond such realism, though vaguely recognised, is not generally appreciated. Our first task here is to assess this need. It is not difficult. Notions such as 'four-dimensional' or 'curved' space are clearly not simple idealisations of everyday life. Though when we speak of them we use familiar words, all such notions – and more generally, all notions of relativity theory – draw their meaning from mathematical physics. In contrast to classical mechanics, the mathematical physics in which such notions come into play cannot itself be seen as merely a quantitative account of relationships between realities which, qualitatively, could be described in everyday language. To pass from near realism to a purely mathematical realism is thus in fact the first step in a process of abstraction to which physics invites us. As we shall see, mathematical realism has had a great many eminent supporters among the physicists of our age. One of the most ardent of them was Einstein.

Classical mechanics also has a characteristic that seems so self-evident to us that generally we do not even notice it is there. I am referring to the fact that it describes the phenomena it deals with as existing in themselves quite independently of the way in which we come to take cognisance of them, that is to say, quite independently of the experimental apparatus which may or may not be set up to that end. Classical mechanics tells us, for example, that between any two solid objects there exists a force proportional to the inverse square of the distance between them. Now a claim of this kind obviously implies that such a force exists whether we observe it or not, and that therefore if it is observed (if we note the relative acceleration the two objects are subject to, for instance) its various characteristics in no way depend on the instruments used in the observation.

Does relativistic classical mechanics have the same characteristics? This question has led to some argument because Einstein, its creator, from the start gave a major role in his reasoning to the observer. However it seems that relativity, both special and general, can also be seen as describing phenomena ('events') which exist in themselves and which various observers only 'see' – so to speak – from different viewpoints. This at least seems to have been Einstein's own position; it is what enabled him to adhere without contradiction to the thesis of mathematical realism.

And where does quantum mechanics stand in all this? It is well known that Einstein could never accept what is called quantum, as opposed to 'classical', physics. Why was that?

There are some rather simplistic ideas abroad on this matter. They turn on his familiar quip that 'God does not play dice' and consist in the belief that of the characteristics of quantum mechanics quantum indeterminism was the main – perhaps the only – one he refused to accept. Now it is quite true that he was more inclined to the determinist thesis than the indeterminist one. However, a thorough study of his writings shows that a much more profound reason for his reservations lay in the acute tension he soon detected between quantum mechanics on the one hand and the notions, for him interrelated, of reality and localisation on the other. To keep the explanation short, we need merely recall that in Einsteinian relativity the notion of *event* is central. It would not be too crude an over-simplification to say that Einsteinian relativity boils down to combinations of events. Now an event is of course *local*: it is defined in terms of a point in the space-time continuum. The mathematical realism of relativity thus tends to elevate essentially local entities to the status of absolutes (or elements of reality-in-itself), perhaps even conceives of them as the only absolutes. (In this connection it should be borne in mind that carrying out a measurement is also an event or, in other words, is local.)

Now from this point of view, and moreover from that of common sense, quantum physics soon raises serious problem. Here in this Introduction is not the place to enter into any technical arguments. But if, as an example, we take the elementary formulation of quantum mechanics, which is based on the notion of the wave function, we encounter the well-known problem which arises from the fact that it is very hard to avoid using the notion of the *collapse* of a wave function occurring when a measurement is made. If as is often the case the wave function has, before the measurement is made, appreciable values in places distant from each other, the effect of the collapse is generally to change these values immediately and considerably, even at points far from the place where the measurement was actually made. Is this instantaneous non-local effect a physical phenomenon or not? The answer depends on how we interpret the wave function in question – which will be discussed later. Suffice to say at this point that there is no simple way of getting rid of the problem.

Might we not object that Bohr long ago answered all such Einsteinian questioning concerning wave function collapse and related themes? In a way this is so, but his answer includes a vital element without which it would not make sense. This remarkable element is quite simply the abandonment of the idea, which as we have seen is implicit in classical physics, that the various phenomena science describes for us all have an existence in themselves, quite independent of whether and of how they are observed. To give concrete form to his idea, Bohr explicitly proposed that the word 'phenomenon' be severely restricted in meaning and use: that it be used only to refer to 'observations made in well specified circumstances, including the description of the whole experimental set-up' [1].

This proposal of Bohr's has considerable implications. It means, for example, that the quantum systems we call 'particles' (electrons, quarks, etc.) and which are said to constitute objects have no properties (indeed, in relativistic physics, scarcely any existence) *in themselves*. These they have solely *for us*, and this in ways that depend on the kind of instrument by means of which they are observed. Further, in certain cases the experimental apparatus may well include several measuring devices set up at whatever distance from each other we may desire. In such cases, Bohr's proposal clearly implies some sort of evacuation of the meaning of the world 'local'. As we can see, it is a long way from the mathematical realism of Einstein.

For a long time, physicists gave up the idea of digging more deeply into such questions, finding that in their eyes they had taken too philosophical a turn. For them there was, and still is, a more urgent need: to make use of the calculation rules of quantum physics in the very many domains where prodigious advances were and still are possible thanks to that wonderful tool. Many of them, moreover, were developing a conviction which though often tacit was none the less genuine: that it is still possible to believe in locality (which if abandoned in certain cases has extraordinary consequences as regards admissible world-pictures) provided only that it is not to be introduced into any reasoning process in quantum physics. Since it could not be put to any use, the idea remained for the most part unformulated. If it had been formulated however, it could well have been couched in terms that could be outlined as follows: 'On the one hand there is quantum mechanics, which provides calculation rules applicable to empirical data and of undoubted validity but which if interpreted in too realist a way are non-local. On the other hand there is reality-in-itself, which could well be composed of some subquantum medium at present inaccessible to experiment but which it is not impossible to conceive as localised.' Such an idea ultimately permitted retention of a world-picture which conformed to the great post-Galilean scientific options (mechanism) without being too much perturbed by the truly strange ideas of Niels Bohr.

Now, as we shall see, an intellectual 'fall-back position' of that kind is no longer tenable. Bell's theorem establishes beyond all possible doubt that any (mathematical) realism of which it is required that it should not contradict the verifiable (in principle at least) and unquestioned predictions of quantum mechanics must necessarily be non-local. This is because of the following reason. If the locality hypothesis were right some correlations at a distance observed in certain circumstances between simultaneous events could only be due to common causes differing from one case to another. Now, for some such correlations the theorem in question shows that if they *were* due to common causes, certain inequalities between measurable numbers would necessarily hold true. However, according *both* to the predictions based on the rules of quantum mechanics *and* to the experimental findings these inequalities are violated.

If the 'common cause' explanation is ruled out, to what can we attribute the observed correlations? The only way out of the predicament is to assume instantaneous transmission of influences over long distances. This means that a consistent realist who believes in the existence of an external reality embedded in space-time can picture it only as one in which such instantaneous influences at a distance do in some circumstances occur. In other words, he must picture it as violating the laws of relativity.

This is the fact of the matter. But here an extremely important point must be borne in mind. It can be shown that such 'relativity-violating' influences at a distance cannot serve to transmit any utilisable signal. In other terms, they are, in that sense at least, inobservable.

This point is in fact important from two points of view. First, it 'rehabilitates' relativity, so to speak – at least as an operational theory: anyone taking into account only 'phenomena' in the restricted sense Bohr gave the term can and must retain the complete relativistic formalism as it stands. Second, and more importantly, it shows that a careful distinction must be made between the *real* and the *observable*. Unless we discard altogether the very idea of a reality that is independent of our knowledge, we have to accept that such a reality cannot be identified with the ensemble of phenomena. This in turn means that we cannot escape what I claim is the fundamental distinction between reality *in itself* or *as such* – reality independent of human minds – and the ensemble of phenomena – or *empirical* reality. As we shall see, this distinction is not for the use of philosophers alone. Scientists seeking to understand in depth the nature of certain debates internal to the scientific community will also find it useful.

Although conducted only in summary fashion, with elaborations left till later, the preceding discussion should already serve to suggest that the distinction just drawn has important implications for the idea of cause and the related idea of explanation. It will also become apparent that it has consequences for the problem of complexity and the closely-connected matter of time.

As regards cause, in the eighteenth century the philosopher David Hume pointed to the conceptual difficulties surrounding the notion; since then the questions raised about it have always been acute. On some occasions it was rejected in favour of the notion of law, on others it played (and still plays) a central role in extremely precise physico-technical developments such as signal theory and dispersion relations. In our own day as in the past, it raises conceptual problems that go beyond the merely technical, questions such as 'should we or should we not distinguish between the idea of causation and that of explanation?' We shall see what light can be thrown on such problems by the distinction between independent and empirical reality. The whole business, it will emerge, has considerable ramifications.

As regards time, a very old and very difficult problem came recently to the fore once more as a result of great progress made in our understanding of complex out-of-equilibrium phenomena. Is irreversible time, the time in which, so we feel, we actually 'live', a reality or an illusion? (We know that the time which figures in the equations of Newtonian mechanics, electrodynamics and so on is 'reversible'.) Here to distinguish between the two realities adds new and it would seem truly significant elements to the discussion. Indeed, these elements cast light not only on the questions we have mentioned but on others as well, such as those of consciousness and of freedom.

A few further remarks should help set the tone of the book. One is by way of a warning. It is important to avoid believing that questions which are in fact closed are somehow open. The seductiveness of what glitters, referred to briefly above, sometimes leads us to see the world as younger than it really is. We may imagine that to reach the truth we only need to come up with brilliant ideas, or at very least (since 'reaching the truth' is after all a rather ambitious aim) that we need only think brilliantly for our thoughts to be valuable and to open fruitful possibilities. In some respects, such an illusion is beneficial, since it guards against discouragement and it maintains some kind of a link between the public at large and genuinely creative thinking. In countries where the illusion is less powerful, those who contribute to the advance of knowledge tend to be even more cut off from the wider world, since what they have to say is seen as too difficult to be accessible to those who are not experts. This leads to a rather sad divorce between silent experts and talkative communicators which at least in this country (France) is rendered less acute by the quaint notion that glitter can be productive (for this notion increases the credibility of the view that even laymen are capable of understanding and appraising arguments on questions of a conceptual kind). But in effect it remains illusory to hope that in our day people can still make valid claims on matters such as reality, time and causality if these claims are not rooted in the extraordinarily elaborate factual knowledge now at our disposal.

A second remark is of quite a different order. Non-scientists whose work brings them into day-to-day contact with scientists often react with mixed feelings to the claims of these scientists. Once the non-scientists have succeeded to some extent in explaining what they have in mind, it becomes apparent that what they are experiencing is a want of intellectual satisfaction. The burden of what they have to say is that while they accept that credence should not be given to the charlatans and false prophets who dress physics in bright colours, and put into its mouth any words they like, at the same time they feel that serious scientists – at least in their scientific discourse – have stripped the world of all taste, smell and succulence. Yet they *know*, directly and therefore authentically, that this is indeed a world full of colour and of solid, subtle and disturbing realities which earlier philosophies, to say nothing of religions, managed to incorporate into their systems of thought. How is it, they ask, that scientists who claim to have taken over from such systems, are no longer able to do so and, what is worse, why do they no longer even understand the general sense of such a question?

To such anxious questioning one may conceive *a priori* of at least three kinds of response. The first would consist, in outline, of claiming that immediate knowledge, or what is said to be immediate knowledge and displays all the appearances of it, may well be nevertheless quite inauthentic; the human mind can create spontaneously concepts that are false in that they are quite ill-fitted to the description of reality. *A posteriori*, science will correct such things . . . A second, less discouraging kind of response is to stress that science is not yet complete and that its findings will not remain eternally bleak. Optimists may consider that the recent advances in the field of complexity open the way to developments along those lines. To borrow an idea from mathematics, we could say that the recently-created concept of *fractals*, which enable mathematicians to model forms such as branches, shores or clouds, provides some notion of what might happen there. And it is also possible to imagine a third kind of response, by no means incompatible with those mentioned so far, which would emerge if it seemed likely – *a posteriori* of course, after close study of the facts and the rules linking them – that the whole of communicable experience (which constitutes the object of science) cannot be equated with the whole of what *is*. The distinction between reality-in-itself and empirical reality clearly opens new perspectives in that direction.

A final remark should help explain why the text includes, on certain questions, elaborations that might seem pointless or needlessly detailed. Talking to a number of people about the problems tackled here soon reveals that most of them have adopted one of two possible but irreconcilable *a priori* positions, which I call the *physicalist* and the *mentalist* stances. Those adopting the first see the existence of a knowable independent reality – which it is the specific task of science to acquaint us with – as a primary self-evident truth whose renunciation would in their eyes render us guilty of a kind of intellectual abdication. For those who adopt the second position – who are almost as numerous as those adopting the physicalist stance – the primary self-evident truth is by contrast the view that any scientific concept is a construct. Human beings can speak only of what they feel, observe or do – in short, of what they experience; so their science can only be an account of that experience, in the broad sense. Both theses are defensible. What is irritating is, as noted, that all too often they operate as unspoken *a priori* assumptions, the intellectual equivalent of taboos, in that they induce immediate rejection of any argument not built from the beginning on whichever of the two positions the person concerned has adopted. It is because of the fact that I have observed most people adopting one or other of these positions, and so have been helped to move beyond both as such, that I find it necessary to spell out some arguments which could (wrongly, in my view) be considered obvious by those who unconsciously share either one of these assumptions.

There are three parts to this book. Part I, Chapters 1–3, deals with what could be called 'the philosophy of experience', or 'the positivism of the physicists', or even 'instrumentalism', if by that word we understand the view that theory (possibly in a highly mathematical form) is essentially an instrument for predicting the results of empirical investigations. Such a philosophy has attracted a great deal of criticism, some justified, some not. It is important to examine it thoroughly right at the beginning, for whether we deplore it or delight in it, the fact is that this philosophy is basic to all current work in theoretical physics.

Part II, Chapters 4–6, is devoted to realism, more precisely to the conception I call 'physical' or 'mathematical' realism. This is a modern version of what in traditional philosophy is sometimes called transcendental realism – the view that there is no essential distinction to be drawn between reality in itself and the ensemble of phenomena. After a period of eclipse, this view returned to favour after the Second World War, at least in the epistemological circles where Karl Popper's influence was dominant. When considered in the light of recent findings in physics, this kind of realism proves difficult to sustain, even in its fallibilist form. So it should come as no surprise that certain chapters in this part of the book, notably Chapter 6, are rather negative in tone (they can be omitted on first reading). It is only when one has thought one's way to the conclusion that a particular idea, though quite natural or seductive in appearance, is in fact untenable that one becomes disposed to take seriously certain other ideas at first glance less plausible but for that very reason capable, if they turn out to be sound, of opening up new horizons.

Part III, Chapters 7–12, is concerned specifically with these new horizons. It examines the problems associated with complexity and the irreversibility of time, seen in the light of the findings of Parts I and II.

Some rather bold ideas of certain contemporary physicists, which have led them (via fully-rational, rigorously argued paths, be it noted) to extreme and mutually incompatible conclusions, are explored in some detail. An extended series of diverse questions (on science and metaphysics, rationality, universality, and the like) are then asked and answered, and finally some insights opened by the new perspectives are suggested.

In approaching the matters raised in the final chapters, extreme caution is advisable. Facts and the principles linking them together are our sheet anchor in such uncertain waters and should never be abandoned. Fortunately, keeping scrupulously to that rule not only does not stop the flow of ideas but even brings them – as we shall see – flooding forward in a way that would be regrettable to hold back. (This last part is where new vistas are mostly opened out; the reader particularly interested in these may like to read it first.)

A note for theoretical physicists

This book, it will have become apparent, is not intended merely for specialists outside my own field. It is also addressed to those in the domain in which I work, theoretical physics. Naturally I would like it to help colleagues in that field better to define the particular concerns of their discipline, perhaps suggesting new lines of research using the techniques of that discipline. I must however point out that it is precisely at such a technical level that I had to compromise here. Every reader, whatever his or her speciality, had to be introduced to the essential features that, in the basic substance of our discipline lead to well-formulated and philosophically interesting problems – and make it possible for us to examine them fruitfully. The book had to be directed firmly towards the discussion of these philosophical aspects, for that is why it was written. That being so, a systematic and exhaustive examination of all the detailed technical questions which in the general opinion of specialists, myself included, can legitimately be asked about the use of the various algorithms and procedures referred to in the text would have been out of place. The book would unavoidably have become very long, would have bristled with technicalities, and would not only have discouraged specialists in other fields but also run the risk of obscuring the real problems even from theoretical physicists . . .

The compromise I have been obliged to make is to refer readers who are theorists to other writings of mine in which the technical details in question (which have not, of course, been lost from sight) are treated thoroughly. The main ones [2] are a long article in the journal *Physics Reports* (henceforth referred to as [2A]) written specifically for this purpose, and an earlier book, *Conceptual Foundations of Quantum Mechanics* (henceforth referred to as [2B]). Any theoretical physicist, novice or veteran, who contemplates engaging in either physical analysis or discussion, or use in his own work of those parts of this book in which such technical details are referred to, is invited, lest his efforts risk coming to naught through lack of firm roots, to supplement the present work by those others, together with the references they include.

This suggestion, let me repeat, is intended only for theoretical physicists. It must be stressed that this book is meant to be self-standing as far as any analysis or discussion of all matters not connected with the technical details of the algorithms used in theoretical physics is concerned. In other words, its content is accessible to any enquiring reader who, with regard to such technicalities, is willing to follow the usual practice of trusting in the good judgement of the professional.